Monitoring the decrease of Lake Chad from space

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Abstract

Observations from space of the open water areas within Lake Chad are presented. They complement and sustain the earlier study of Mohler et al. (1989), which demonstrates a decrease of about 90 percent in surface between 1966 and 1986. Further, Meteosat images were processed to obtain weekly maps of albedo following the scheme of Mousssu et al. (1989). The analysis of these maps throughout the year reveals the functioning of the lake as well as the large variability of the open water areas during a year.

Introduction

Lake Chad is a large, closed catchment basin located in the western Sahel (Figure 1), and is part of the borders of the four countries of Cameroon, Chad, Niger and Nigeria. As a closed hydrologic system, fluctuations of Lake Chad serve as an excellent climatic indicator of prolonged drought which has affected the western Sahel since the late 1960's, the third major drought of the region this century (Leroux, 1983; Glantz, 1987). Since 1968, the lake has contracted to less than one-tenth of its maximum 1963 surface area of 23,000 sq km (Grove, 1978).

Lake Chad is intensively studied using remote sensing data from the geostationary satellite Meteosat (Anonymous, 1989; Citeau *et al.*, 1989; Diabaté *et al.*, 1989) and the polar orbiting NOAA satellites (Mohler, Amsbury, 1989; Rigal, 1989). As one of the most prominent features in Africa, it is also often photographied by space crews (Wood, Helfert, 1985; Greer, 1989; Helfert, Lulla, 1989; Lulla, Helfert, 1989). Recently, Mohler *et al.* (1989) published estimates of open water areas in Lake Chad from 1966 to 1986 and showed a decrease of 93 percent in surface during that period. The present note intends to complement their investigations by taking into account some observations published in journals of limited diffusion as well as observations made at *Ecole des Mines de Paris*.

Data and Their Processing

According to Leroux (1983), the climate over Lake Chad is dry, weakly rainy and warm. It offers two seasons: the harmattan season from October to April, and the atlantic monsoon from May to September. Despite the fairly small north-south extension of 210 km of the lake, the climate varies from south to north, the seasons beginning and ending one month later in the north than in the south. Mean annual temperature is about 28° Celsius, with a mean annual variation of about 10° Celsius. Mean annual humidity is close to 30% with a ratio between extreme monthly averages equal to 4. The mean annual total of rainfall amounts to 250 mm in the north and to 500 mm in the south. The seasonal variation is large, with no precipitation during the harmattan season and a peak in August (see Table 1). Of interest are also the precipitations in the south of the lake, over the drainage basin of the Logone and Chari rivers (Table 1). These rivers feed Lake Chad, and contribute, together with their drainage river El Beid, to about 99% of the annual inflow (Kolawole, 1987; Bardinet, Monget, 1980). To conclude this paragraph, it must be stressed that the interannual variability of this area is very large. The atlantic monsoon season can be late or early, stops early or lasts in late fall. Dry periods can also occur during this season, and the amount of rainfall is highly variable.

Observations from Space and Their Processing

In order to study the decrease of the Lake Chad between 1966 and 1986, Mohler *et al.* (1989) selected eight photographs taken by the crews during Gemini, Skylab and Space Shuttle missions. After digitization, the images were registered to a previously digitized map compiled by the

Month	Lake Chad North	Lake Chad South	Logone and Chari Basin
January	< 1	< 1	2
February	< 1	< 1	2
March	< 1	< 1	2
April	< 1	2	5 - 10
May	5	20	30 - 40
June	10	40	50 - 75
July	50	100	125 - 200
August	125	250	300
September	10	50	100 - 150
October	3	10	20 - 50
November	< 1	< 1	1 - 2
December	< 1	< 1	< 1
TOTAL	**250**	**500**	**500 - 1000**

Table 1. Mean monthly rainfall over Lake Chad and the drainage basin of Logone and Chari rivers (in mm). After Leroux (1983).

United States Defense Mapping Agency Topographic Center, and classified as either land or water. The open water area is then estimated for each image.

To complement their work, I add to their findings the estimate made by Wood *et al.* (1989) from another Space Shuttle image. I also use either Meteosat images processed at *Ecole des Mines de Paris,* or some maps derived from satellite data found in articles written in journals of restricted diffusion. From these maps, I compute the open water area when possible, either by using the scale when given, or by comparison to the sizes of Lake Chad itself (see Fig. 1). These articles are the followings.

Mohler and Amsbury (1989) present an AVHRR image which has been processed using both the Normalized Difference Vegetation Index (NDVI) and a kind of classification method, called Comprehensive Analysis for Unitemporal Scene Evaluation. Two large colour pictures allow the mapping of the open water area for April 15, 1985. Rigal (1989) uses two different indexes to classify the objects within AVHRR images of Lake Chad. One is the NDVI and the other, a similar index but constructed from thermal infra-red (channel 5) and near infrared (channel 2). The different behaviours of both indexes permit him to map the open water for late fall 1988 and winter 1989. Citeau *et al.* (1989) map the open water areas for November 1988 using a colour composite of the visible and thermal infrared channels of the Meteosat imagery. Anonymous (1989) shows two maps derived from Meteosat images, November 1988 and April 1989. Processing made at the National Remote Sensing Center, Farnborough, United Kingdom, involves radiometric balancing of image extracts from different dates to compensate for seasonal differences in local solar elevation, followed by density slicing to highlight differences in digital values.

As already said, I make an extensive use of Meteosat

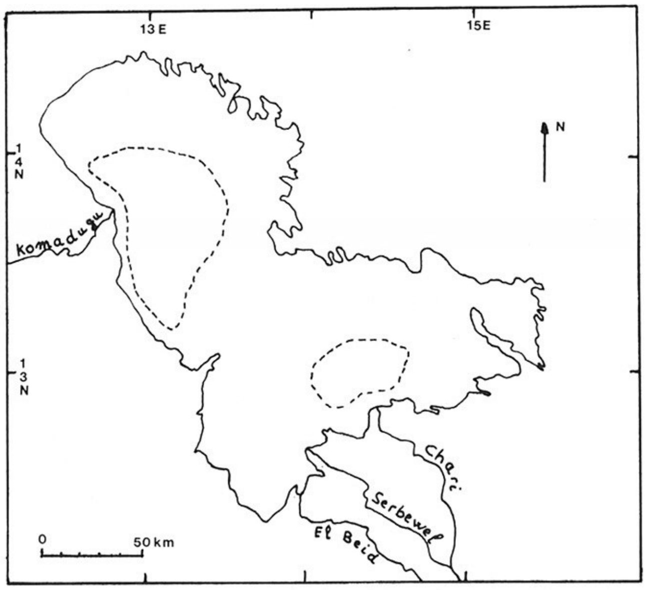

Figure 1 Map of Lake Chad at the beginning of July 1973. The areas surrounded by broken lines denote open water and cover 4,190 sq km. After Chouret *et al.* (1977).

imagery. The Meteosat data originate from the archives of the European Space Agency, or from a direct reception in 1984 using a Secondary Data User Station (SDUS) connected to a personal computer as described by Diabaté *et al.* (1989a) or Wald *et al.* (1990). These images have been processed using the Minimage software library of *Ecole des Mines de Paris*, according to the scheme proposed by Moussu *et al.* (1989) to obtain weekly maps of the ground albedo. Such a methodology has been successfully applied by Diabaté *et al.* (1989b) to Meteosat imagery, to depict the variations both in space and time of the vegetation in Sahel. When applied to Lake Chad, these maps of ground albedo also indicate the open water areas which exhibit low albedo. The albedo increases as the water thickness decreases. Apart the deep water, the lower values characterize the areas composed of water and reed while clay soils show up higher albedos with a dependence upon the soil moisture content and the vegetation coverage. For each weekly map of albedo, the pixels were classified as either open water or not, using a threshold technique applied to the whole image covering part of Sahel as well as parts of the Atlantic Ocean. The threshold was set as being the upper limit of the range of values which characterize the ocean. A small superior margin was allowed to take into account that due to the broad spectral band of Meteosat visible channel (0.4 - 1.1 μm) an increase of the chlorophyll content of the water increases the albedo, because of the response of the green vegetation in near infrared spectral band. According to the relationship between the digital counts of such maps and the actual albedo given by Moussu *et al.* (1989), the albedo of the open water pixels ranges between 0.0 to 0.05. Once the pixels classified, the open water pixels within Lake Chad were counted (Fig. 2). Accuracy in areal estimates has been evaluated to about 20%.

Results

The area estimates made during this study are listed in Table 2, together with the results of Mohler *et al.*. My estimates are in agreement with those of Mohler *et al.* when dates coincide, within the limits of accuracy. Open water areas range from a high of 22,772 sq km during the Gemini mission in June 1966 when Lake Chad was near its historical maximum, to a low of 500 sq km in April 1989. From 1966 to nowadays, Lake Chad had contracted by a factor of about twelve. This is the direct consequence of the prolonged drought affecting Sahel since the late 1960's. Less rain falls on the Logone – Chari basin and Lake Chad itself and therefore the volume of water in the lake is lower than three decades earlier. However, for the last fifteen years, open water areas are quite stable, and no negative trend can be observed furthermore. The areas covered by open water are very often greater in the southern basin than in the northern one, but the reverse occurs from time to time.

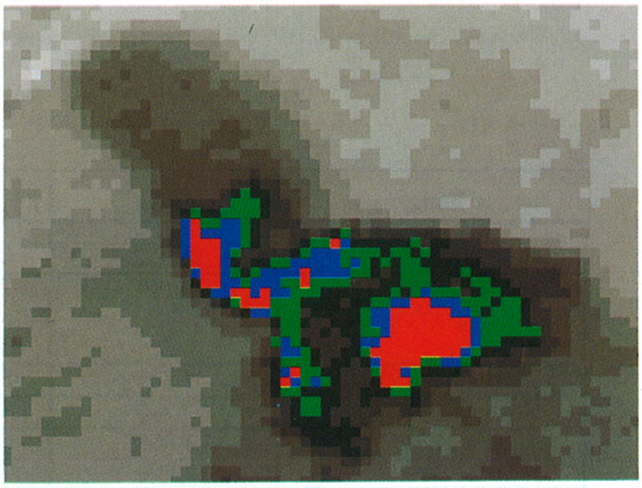

Figure 2 This map of albedo has been obtained from the processing of Meteosat images of December 1985, week 49. Albedo increases from red, blue, green, violin, black to white. Only red pixels are labelled open water and total area amounts to 2,000 sq km. Albedo for red pixels ranges from 0 to 0.05, from 0,05 to 0.07 for blue, 0.07 to 0.09 for green. A change in grey level means a change of 0.02 in albedo.

High variability in open water areas can be observed for a same month from year to year. In Table 3 are computed for each month the average values of the observations available for this month. Of course, data from June 1966 have not been taken into account. The standard deviations are often of small interest because of the low number of observations. This table indicates that the open water areas do vary from year to year and this is in agreement with the variability of the rain falling on Lake Chad itself and on the Logone – Chari basin.

Table 4 illustrates the variability of the open water areas throughout the year 1984. Although in the dry season, January presents a high of 3,000 sq km which is a consequence of the rainfall of the year 1983 as explained later. The dry season goes on and the dessication of the lake increases until May where the open water area reaches a low of 1,000 sq km. Rain begins to fall in June, so that the area is maintained at this low. The increase in rain leads to an increase in open water in summer. The level of water increases more in the southern basin than in the northern one because there is more rain in the south. In October, the rain comes to a halt, and the decrease in the water level indicates that evaporation efficiently begins particularly in the north. Late November the southern basin is fed by the flood of the Logone – Chari – El Beid rivers system. This important but slow supply makes the water level increase to reach a maximum in January.

The observations are well sustained by the works of Rigal and others (see Table 2), who found a low level of water at the beginning of November 1988, following a higher level in October. This level increases with occurrence of the flood and reaches a maximum in winter 1989

Date	Area	Origin of document and of estimates
June 1966	22,772	Gemini mission. In Mohler *et al.* (1989)
July 1973	4,190	This study. After a ground measurements-based map by Chouret *et al.* (1977). (2,330 north and 1,860 south).
September 1973	1,752	Skylab. In Mohler *et al.*
November 1982	2,276	Space Shuttle. In Mohler *et al.*
August 1984	1,655 2,000	Space Shuttle. In Mohler *et al.* This study (see Table 4)
October 1984	1,678 2,050	Space Shuttle. In Mohler *et al.* This study (see Table 4)
November 1984	1,689 1,300	Space Shuttle. In Mohler *et al.* This study (see Table 4)
April 1985	1,653	Space Shuttle. In Mohler *et al.*
15 April 1985	1,200	This study, after Mohler, Amsbury (1989) (1,200 south).
June 85 (Week 22)	1,500	This study. From processing of Meteosat imagery (1,500 south)
Dec. 85 (Week 49)	2,000	This study. From processing of Meteosat imagery (600 north and 1,400 south)
January 1986	4,452	Space Shuttle. In Mohler *et al.*
June 86 (Week 22)	1,200	This study. From processing of Meteosat imagery (1,200 south)
Dec. 86 (Week 49)	2,300	This study. From processing of Meteosat imagery (700 north and 1,600 south)
1 October 1988	1,300	Space Shuttle. In Wood *et al.* (1989)
November 1988	1,490	This study. After Anonymous (1989) (880 north and 610 south)
3 November 1988	1,100	This study. After Rigal (1989) (290 north and 830 south)
11 November 1988	1,200	This study. After Citeau *et al.* (1989) (450 north and 750 south)
24 November 1988	1,800	This study. After Rigal (1989) (640 north and 1,200 south)
14 February 1989	3,140	This study. After Rigal (1989) (1,940 north and 1,200 south)
14 March 1989	1,200	This study. After Rigal (1989) (380 north and 840 south)
11 April 1989	500	This study. After Rigal (1989) (500 south)
April 1989	980	This study. After Anonymous (1989) (440 north and 560 south)

Table 2. Estimates of open water area for Lake Chad according to various observations from space (in sq km).

Month	Number of observations	Mean area (sq km)	Standard (sq km)	Minimum area (sq km)	Maximum area (sq km)
January	2	3,726	-	3,000	4,452
February	2	2,820	-	2,500	3,140
March	2	1,250	-	1,200	1,300
April	5	1,127	381	500	1,653
May	1	1,000	-	1,000	1,000
June	2	1,350	-	1,200	1,500
July	2	2,995	-	1,800	4,190
August	2	1,828	-	1,655	2,000
September	2	1,976	-	1,752	2,200
October	3	1,676	-	1,300	2,050
November	7	1,551	378	1,100	2,276
December	3	1,900	-	1,400	2,300
All data merged	**35**	**1,804**	**834**	**500**	**4,452**

Table 3. Annual variability of the open water areas. Data from June 1966 have not been taken into account.

Month and Week	Total area	Southern basin	Northern basin
January, week 4	3,000	2,100	900
February, week 6	2,500	1,800	700
March, week 10	1,300	1,300	-
April, week 15	1,300	1,300	-
May	1,000	1,000	-
June	1,000	1,000	-
July, week 27	1,800	1,300	500
August	2,000	1,500	500
September	2,200	1,700	500
October, week 42	2,200	1,800	400
October, week 43	1,900	1,600	300
November, week 45	1,200	1,200	-
November, week 47	1,400	1,400	-
December	1,400	1,400	-

Table 4. Estimates of open water area for Lake Chad using Meteosat imagery in 1984 (in sq km).

to decrease sharply in April 1989. Also relevant are my observations of early December 1985 (2,000 sq km) preceding the observations of Mohler *et al.* in January 1986 (4,452 sq km). Table 3 supports these conclusions but reciprocally, they cannot be drawn out from this statistical table because of the low confidence level of its content due to the very weak number of observation.

Conclusion

During the great drought of 1968 to 1974, the water level within Lake Chad fell considerably by about 90%. Since then the lake has not recovered its ancient maximum. For the last few decades, the open water areas amount to an average of about 1,800 sq km, and do not show any sign of further decline.

The seasonal as well as yearly variabilities of the water level are very high, and coincide with those of the rainfalls in this geographical region. During the year, the water level presents two highs and two lows. The first low occurs at the end of the dry season: March – April, and is the absolute minimum observed in the year. Then, the rain falls onto the lake making the water level rises up to a high reached in summer. Once the rain stops, the water level slowly decreases down to a low in November. Then, the Logone – Chari – El Beid rivers system floods in the lake slowly and makes the level rise up to the yearly maximum in January.

Images from space do not reveal the whole recent history of Lake Chad. But they make it possible to monitor daily this particular area. Provided some calibrations of satellite-derived informations are done with relevant ground measurements, the impact of such a monitoring of the local economics is largely evident.

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